SPECIAL TOPICS IN PHYSICAL CHEMISTRY : Mid Term Exam (Fall 2009)

1. Align the following lists in an increasing order of (a) size and (b) time.
(a) [Bacteriophage, Red blood cell, Typical size of protein, E. coli, Diameter of viral capsid, bases, Diameter of nuclear pore, ribosome] (5 pt)
(b) [bond vibration, E coli doubling time, animal lifespans, enzyme reaction, protein folding, protein synthesis] (5 pt)

2. (a) Calculate the molar concentration of a protein X if a single protein X is found in an *E. coli* cell. (5 pt)
(b) How many protein Xs should be present in a yeast cell if the concentration of protein X in the yeast cell is identical to that of *E. Coli* cell ? (5 pt)
(c) In the physiological condition, the molar concentration of sodium ion is 150mM. How many sodium ions are present in *E. Coli* cell? What is the mean spacing between these ions? (5 pt)

3. (a) Calculate the diffusion coefficient (D) of a protein whose diameter is 5 nm in the unit of μm^2/sec and estimate the time it takes for the protein to diffuse the distance of 10 cm (5 pt).
(b) For molecular motors that hydrolyze ATP and move along the cytoskeletal filament with a speed of v = 1 μm/sec, how long does it take to reach the same distance? (5 pt)
(c) Write down the distances reached through (i) diffusion and (ii) directed motion as a function of time *t.* By using the results and parameters obtained in (a) and (b) calculate the moment when directed motion becomes more efficient than the diffusion. (5 pt)

4. The figure shows the pattern of gene expression in the Drosophila embryo that has undergone 13 cycles of cell division. Assuming that at this stage of the development all the cells after division lie on the surface of embryo, estimate the number of cells participating in each stripe. (10 pt)

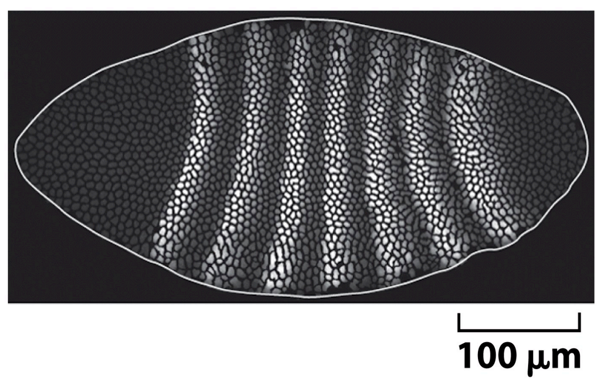

Figure 2.35 Physical Biology of the Cell (© Garland Science 2009)

5. Estimate the protein synthesis rates of *E. coli* during a cell cycle by including the effect of protein degradation. For simplicity, assume that all proteins are degraded at the same rate with a half-life of 60 min and work out the number of ribosomes needed to produce the protein content of a new bacterium given that part of the synthesis is required for the replacement of degraded proteins. (15 pt)

6. RNA polymerase and ribosomes (20 pt)

(a) If RNA polymerase subunits β and β' together constitute approximately 0.5 % of the total mass of protein in an *E. coli* cell, how many RNA polymerase molecules are there per cell, assuming each β and β' subunit within the cell is found in a complete RNA polymerase molecule? The subunits have a mass of 150 kDa each. (5pt)

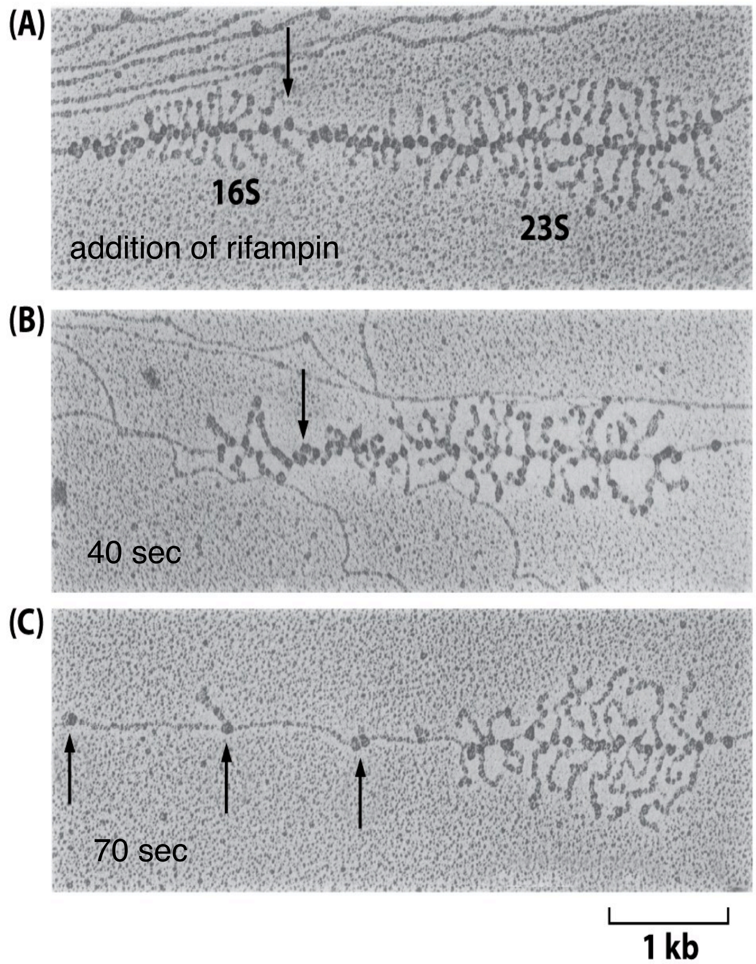

Figure 3.29 Physical Biology of the Cell (© Garland Science 2009)

(b)Rifampin is an antibiotic used to treat Mycobacterium infections such as tuberculosis. It inhibits the initiation of transcription, but not the elongation of RNA transcripts. The time evolution of an *E. coli* ribosomal RNA (rRNA) operon after addition of rifampin is shown in the figure (A)-(C). An operon is a collection of genes transcribed as a single unit. Use the figure to estimate the rate of transcript elongation. Use the beginning of the "Christmas tree" morphology on the left of Figure (A) as the starting point for transcription. (5 pt)

(c) Using the calculated elongation rate estimate the frequency of initiation off of the rRNA operon. These genes are amongst the most transcribed in *E. coli. (5 pt)*

(d) A typical *E. coli* cell has a division time of 3000 sec and contains 20,000 ribosomes. Assuming there is no ribosome degradation, how many RNA polymerase molecules must be synthesizing rRNA at any instant? What percentage of the RNA polymerase molecules in *E. coli* are involving in transcribing rRNA genes? (5 pt)

7. Imagine that our DNA molecule has a total of N binding sites, N_p of which are occupied by the protein of interest. Assuming that the binding energies when the proteins are bound nonspecifically are the same regardless of which nonspecific sites are occupied, calculate the entropy (S) of the system as a function of the ratio $c=N_p/N$ (Hint : Use Stirling approximation. $\log x! = x \log x - x$ for $x \gg 1$). At what value of c does the S reach its maximum value? (15 pt)

Table 1.1 Rules of thumb for biological estimates

	Quantity of interest	Symbol	Rule of thumb
E. coli	Cell volume	$V_{E.\ coli}$	$\approx 1\ \mu m^3$
	Cell mass	$m_{E.\ coli}$	≈ 1 pg
	Cell cycle time	$t_{E.\ coli}$	≈ 3000 s
	Cell surface area	$A_{E.\ coli}$	$\approx 6\ \mu m^2$
	Genome length	$N_{bp}^{E.\ coli}$	$\approx 5 \times 10^6$ bp
	Swimming speed	$v_{E.\ coli}$	$\approx 20\ \mu m/s$
Yeast	Volume of cell	V_{yeast}	$\approx 60\ \mu m^3$
	Mass of cell	m_{yeast}	≈ 60 pg
	Diameter of cell	d_{yeast}	$\approx 5\ \mu m$
	Cell cycle time	t_{yeast}	≈ 200 min
	Genome length	N_{bp}^{yeast}	$\approx 10^7$ bp
Organelles	Diameter of nucleus	$d_{nucleus}$	$\approx 5\ \mu m$
	Length of mitochondrion	l_{mito}	$\approx 2\ \mu m$
	Diameter of transport vesicles	$d_{vesicle}$	≈ 50 nm
Water	Volume of molecule	V_{H_2O}	$\approx 10^{-2}\ nm^3$
	Density of water	ρ	1 g/cm^3
	Viscosity of water	η	≈ 1 centipoise (10^{-2} g/(cm s))
	Hydrophobic embedding energy	$\approx E_{hydr}$	25 cal/(mol Å^2)
DNA	Length per base pair	l_{bp}	$\approx 1/3$ nm
	Volume per base pair	V_{bp}	$\approx 1\ nm^3$
	Charge density	λ_{DNA}	2 e/0.34 nm
	Persistence length	ξ_P	50 nm
Amino acids and proteins	Radius of "average" protein	$r_{protein}$	≈ 2 nm
	Volume of "average" protein	$V_{protein}$	$\approx 25\ nm^3$
	Mass of "average" amino acid	M_{aa}	≈ 100 Da
	Mass of "average" protein	$M_{protein}$	$\approx 30{,}000$ Da
	Protein concentration in cytoplasm	$c_{protein}$	≈ 300 mg/mL
	Characteristic force of protein motor	F_{motor}	≈ 5 pN
	Characteristic speed of protein motor	v_{motor}	≈ 200 nm/s
	Diffusion constant of "average" protein	$D_{protein}$	$\approx 100\ \mu m^2/s$
Lipid bilayers	Thickness of lipid bilayer	d	≈ 5 nm
	Area per molecule	A_{lipid}	$\approx \frac{1}{2}\ nm^2$
	Mass of lipid molecule	m_{lipid}	≈ 800 Da